OPTICAL COMMUNICATIONS LINK

Technical Field

The present invention is directed to a movable optical communications link having at least one optical fiber, in particular for use in transmitting information or performing interferometric measurements.

Background of the Invention

Optical fiber links used to transmit information via light have significant advantages, both for long transmission links in telecommunications, as well as for short transmission links inside buildings, vehicles, and machines, not to mention in electronic calculating machines, since they ensure high data transmission density accompanied by low power losses. Due to their thin, flexible, but mechanically very durable construction, incoming optical fiber lines and outgoing optical fiber lines are beneficial, particularly for connecting optical sensors for measuring physical parameters, such as pressure and temperature, etc. In addition, unlike electrical connections, they cannot cause any electrical sparkovers or short circuits. The high transmission capacity of the optical fibers makes it possible to modify or replace the sensors and measuring devices without having to replace the communication links. This can result in considerable cost savings in vehicles, buildings, machines, or production facilities. There is often the need for optical fiber links to be mechanically movable, such as when installed in robots. In buildings and vehicles, as well, one frequently

encounters motion among components due to strain or expansion.

Therefore, optical fiber links for transmitting information are always of great benefit when there is a need to transmit high information densities and a mechanically flexible connection is required, since the distance between the sender and receiver of the information varies as a function of time.

Here, the problem arises that significant changes in the position of the transmitter and/or of the receiver, and, in particular, in their relative distance spanned by optical communication links constituted as simple cable, can cause the entire system, such as a remote-controlled robot, to be obstructed by the requisite reserved length of cable. It can happen that individual components, which communicate with one another via an optical communications link, become mechanically blocked by loops of cable. Another problem is that one can end up with a "cable salad".

Another problem encountered in response to variations in the position and distance of transmitters and/or receivers has to do with the nature of the optical transmission signal:

In communications transmissions of high quality and transmission frequency, it is necessary to control the polarization state of the optical information flow in the optical fiber, as well as in the other optical components. In the case of coherent transmissions, for example, phase-coherent mixing of the optical information flow with other light sources must be carried out. This is only optimal when the polarization states are

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substantially identical. When working with high bit-rate transmissions, the polarization mode dispersion of the fibers limits the reception quality, and transmission frequency can only be increased by carefully controlling the polarization. In many other optical components as well, the performance is a function of the polarization of the light.

Generally, the polarization state of the light in an optical fiber is not constant. Each glass fiber has a certain elliptical birefringence, so that the polarization of the light continually changes in the fiber. This variation propagates through to the end of the fiber, and, since it is dependent upon the spatial geometry of the fiber curve, the polarization state at the output end of a moving fiber varies with the motion.

In known methods heretofore, this polarization effect is avoided in that the optical communications transmission takes place in one of the intrinsic modes of a polarization-maintaining fiber. These polarization-maintaining fibers are characterized by pronounced birefringence, so that there is virtually no coupling over between the two polarization modes in the fiber. Since a change in the polarization of the light in an optical fiber is a phase shift effect between the intrinsic modes of the light, the polarization mode dispersion does not occur when the light in the fiber propagates through permanently in one intrinsic mode only.

The drawback of this method is that the polarization-maintaining fibers are expensive. Moreover, the light must be launched at the input ends of the polarization-maintaining fiber in a defined polarization

state.

Technical Object

The object of the present invention is, therefore, to provide an optical communications link which will overcome the described problems. In particular, to ensure a high transmission quality, the polarization state of the light should not depend substantially on changes in the form of the communications link and, therefore, on changes in the position of the transmitters and receivers. In addition, the communications link should be easily adaptable to changes in form, in particular to variations in length, but, it in this context, always be characterized by a straightforward arrangement.

Detailed Description of the Invention

The objective is achieved by an optical communications link having at least one optical fiber, in particular for communications transmission, where the optical fiber is repeatedly bent and, in the process, is wound in a helical shape, alternating as a right-hand and left-hand helix, fiber sections having a right and left curvature being distributed in such a way over the communications link that the average torsion of the fiber over the communications link is approximately zero.

Thus, the optical communications link of the present invention is designed in such a way that the sensitivity of the polarization state of the optical transmission signal to changes in the form of the communications link and, i.e., of the optical fibers is substantially compensated. This is assured by the present invention in that the optical fiber is repeatedly bent, fiber sections

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having left-hand and right-hand curvature being distributed in such a way over the communications link that the average torsion of the fiber over the communications link is more or less zero. Preferably, this also holds for individual subsections of the fiber, so that left and right curvatures are uniformly distributed over the fiber. By preference, the fiber is wound in a helical shape, alternating with a right-hand and left-hand helix. Mixed forms having an even meander shape are also possible.

The basis of this invention is the motion-and form-dependent birefringence of an optical fiber: the linear birefringence is heavily dependent upon the ellipticity are the fiber core, less heavily dependent upon the bend of the fiber, and hardly dependent upon the helical winding, given a large radius of the fiber. In contrast, the circular birefringence is hardly dependent upon the ellipticity of the fiber core and on the curve of the fiber, on the other hand, very heavily dependent upon the helical winding of the fiber. The main reason for the form dependency of the polarization state at the output end of an optical fiber is the considerable dependency of the fiber's optical activity upon the exact form of its helical windings. In the first approximation, this effect is achromatic and does not result in any polarization mode dispersion. It is caused by one of the so-called optical Berry phases, the "spin redirection phase" (R.Y. Chiao, Y.S. Wu, Phys. Rev. Lett. 57, 933 (1986)). This Berry phase (or geometric phase) is a phase effect produced by the structure of the fiber's space curve and not by an optical path, as is the case with the normal dynamic phase of the light. Nevertheless, with respect to interference of the light, geometric phases have the same properties as the normal dynamic phase.

The size of the spin redirection phase in a helically wound fiber is equivalent to the solid angle Ω that the k vector (k corresponds to the propagation constant β in the technical literature) wraps around on the sphere of the light-propagation orientations in the counter clockwise-direction when the light in the fiber is directed through a helical winding. The spin redirection phase is additive and changes its operational sign when the helical direction of the fiber changes, e.g., from the left-hand to the right-hand helix.

To minimize this form-dependent polarization effect, the fiber must be made up of wound fiber sections having alternating winding directions. As an example, the fiber sections are alternately wound to the right and to the left, the space angle, which wraps around the k vector in the left-hand wound sections, being equivalent to the space angle that the k vector wraps around in the right-hand wound sections. In the simplest case, the fiber alternately follows a right-hand and then a left-hand helix, each time with an equivalent length and winding; or right-hand and left-hand wound fiber sections of a fixed length alternate with each other.

To reduce the polarization dependency of changes in the form of the fiber link, the sections having right-hand and left-hand helical winding of the fiber must be distributed over the fiber in such a way that, in response to an altered fiber form, the changes $d\Omega_i$ in the solid angles Ω_i of the k vectors in the i-th fiber section add up to zero, thus to

$\Sigma\ d\Omega_i = 0$.

The variation in the polarization of an optical signal at the output end of a moving optical communications link

having one optical fiber is advantageously reduced in that the optical fiber is repeatedly bent, fiber sections having a right and left curvature being distributed in such a way over the communications link that the average torsion of the fiber over the communications link is approximately zero.

In order to minimize the variation in polarization in the case of changes in the form of only one fiber section, the optical fiber is preferably bent in such a way that the torsion of the subsection averaged over subsections of the communications link is approximately zero. In this context, a subsection is a fiber section which is at least sufficiently long to contain right-hand and left-hand fiber segments, e.g., two successive, individual right-hand and left-hand windings, the torsion of the two sections canceling each other.

The optical fiber is advantageously coiled with alternating winding direction around an even number of, preferably two, side-by-side carrier elements. In this context, one or a plurality of left-hand windings around one of the carrier elements can follow the corresponding number of right-hand windings around another carrier element.

Another embodiment of the communications link provides for two helically wound optical fibers (1, 3, 6) having different winding directions in order to direct the light in the forward and return directions.

In this further embodiment, the communications link has at least two helically wound optical fibers having different winding directions to direct the light in the forward and return directions. In this context, both

optical fibers can be advantageously wound around the same carrier element, the outer winding of the two windings having a somewhat larger coil pitch, so that, in terms of absolute value, the torsion of the forward and return line is more or less equivalent, but with different operational signs.

Thus, the communications link in accordance with the present invention permits the transmission of information in moving fibers, with a substantially reduced polarization variation at the output end.

To minimize the effects of the bending- and stress-induced birefringence of the fiber material on the polarization state of the transmission signal, one should not select too small of a winding radius for the optical fibers. Preferably, it should amount to at least 2 cm, in particular to at least 3 cm.

In a further advantageous embodiment of the present invention, the optical fiber is joined to an elastic carrier material, which, in response to mechanical loading, permits a change in the form of the transmission line and, in response to the lack of a mechanical load, retains the optical fiber in its initial curved form.

This communications link makes it possible to establish a connection that is compact, yet movable and variable in length, for transferring optical data between a transmitter and a receiver. In this manner, one minimizes any mechanical hindrance to the overall device, including the transmitter, receiver and communications link. Furthermore, the output signal is substantially insensitive to any changes in the form of the communications link.

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By preference, the optical fiber is wound in a helical shape, e.g., in the manner of a telephone cable. In response to stress in the longitudinal direction of the helix, i.e., of the meander shape, the communications link can be pulled apart in an accordion-like fashion, and, in response to cancellation of the stress, again assumes its compact, initial form.

In another advantageous further refinement, the optical fiber is wound around at least one elongated carrier element, such as a cylinder. The carrier element is preferably flexible. As an example, the carrier element is a flexible bar.

To realize and stabilize its curved form, the fiber is preferably secured to the carrier element in such a way that it is movable in its wound form, but remains stabilized on the carrier element, e.g., in that it is flush mounted on the carrier element or embedded between the carrier element and a cladding material.

The following is a brief description of the drawing, whose figures show:

Figures 1 through 3	examples of the transmission lines according to the present invention for reducing the influence of form on the polarization of the output signal.

Figures 1 through 3 illustrate examples of transmission lines according to the present invention which are compact, movable, and flexible. Furthermore, they are designed to minimize the influence of the transmission

line's form on the polarization of the output signal. Thus, they are especially suited for linking optical transmitters and receivers, which are movable with respect to one another, for purposes of data communications.

The top part of Figure 1 shows a detail of such a communications link, which is made up of a cylinder 2, as a carrier material or carrier element, and of an optical fiber 1. Optical fiber 1 is helically wound around cylinder 2, the direction of the helical winding changing, for instance, in the middle of the cylinder at point B. Thus, in the left part of the communications link, the torsion of the optical fiber is negative, in the right part, positive, so that the average torsion is more or less zero.

To change the direction of the helical winding on a cylinder, an arc B must be wound. This arc is secured, together with the remaining right- and left-hand winding, for example, by adhesive or by tying it to the cylinder, since otherwise it would become detached.

To manufacture a long communications link, a plurality of line segments can be joined to one another, as shown in Figure 1. The depicted fiber segment is then a subsection, in which the average torsion is approximately zero.

In the lower part of Figure 1, the k vector of the light launched into the fiber and the corresponding solid angle Ω are shown. If r(s) denotes the space curve described by the fiber as a function of the arc length s, then solid angle Ω is derived as a measure for the Berry phase from the torsion τ of the space curve, as follows (s_1, s_2

denote the beginning and end, respectively, of the fiber):

$$\int_{s1}^{s2} \tau(s)ds = \Omega \propto \Phi_{\mathrm{Berry}}, \text{ where } k(s1) = k(s2)$$

Two further examples of communications links or of sections thereof, in accordance with the present invention, are shown in Figure 2. In Figure 2A, optical fiber 3 is doubly wound over two cylinders 4, 5. Around cylinder 4, fiber 3 describes a left-hand winding (L), around cylinder 5, a right-hand winding (R). By alternating the two cylinders, a right-hand helical winding and a left-hand helical winding always alternate with one another.

In this context, glass fiber 3 is embedded, similarly to a telephone line, in a material which has dimensional stability, but is highly elastic, so that the incoming line can be pulled apart in accordion-like fashion, but contracts again when the tensional force subsides. In addition, cylinders 4, 5 can themselves be resilient to facilitate a lateral motion of the communications link.

The optical signal can be conducted in the reverse direction through the same glass fiber, however, over a different spectral channel, for example. Since the geometric phase is achromatic, and a right-hand helix (left-hand helix) remains a right-hand helix (left-hand helix) when it is propagated through in the opposite direction, the same compensation effect occurs for the optical forward and reverse line as does for the form-dependent polarization fluctuations.

In place of two cylinder windings as shown in Figure 2A, the fiber can also be routed over more cylinders, i.e., four cylinders 7, 8, 9, 10. This is shown in Figure 2B. In the case of 2B, right-hand and left-hand loops alternate, each characterized by R or L.

It is also fundamentally possible for a plurality of left-hand loops to follow a plurality of right-hand loops in that the fiber is repeatedly wound around a cylinder before it is routed to the next cylinder with an opposite winding direction. It is crucial here that the formula $\Sigma\, d\Omega_i=0$ remain satisfied, and that the torsion of the entire optical fiber be compensated.

The achromaticity of the geometric phase makes it possible to use both white light sources, as well as more or less monochromatic light sources.

In the case that the light is directed in the forward and reverse direction through the same communications link, it is possible to configure two cylinder windings side-by-side, one of these, a right-hand helix, functioning as an incoming line, and the other, a left-hand helix, as a return line. The flexible claddings, which determine the form elasticity of the line, can be configured separately from one another. However, they are advantageously designed as contiguous claddings. This prevents them from separating from another, thereby permitting them to jointly participate in the motion of the line, substantially identically.